Enhanced Predictions of Time to Critical Dielectric Breakdown of Materials Under Prolonged Exposure to Space Plasma Environments

Completed Technology Project (2014 - 2018)

Project Introduction

The leading cause of spacecraft failures and malfunctions due to interactions with the space plasma environment is electrostatic discharge (ESD). The enhanced time to ESD model I propose will allow for better predictions of spacecraft lifetimes and reduce the time and effort needed to obtain them. Spacecraft in the space plasma environment accumulate charge over time, the lack of electrical ground and low charge mobility can cause strong localized electric fields to build up in a material that can eventually lead to catastrophic breakdown. As spacecraft with longer mission lifetimes and more sensitive instruments are proposed, it becomes increasingly more important to be able to predict the operational lifetime of materials used in harsh space environments. My research will be to perform material tests in order to develop an enhanced ESD breakdown model. The Utah State University Materials Physics Group (MPG) has studied the charge transport properties of spacecraft materials in partnership with NASA facilities including Goddard and Marshall Space Flight Centers, the Jet Propulsion Laboratory and the Air Force Research Laboratory. As part of my participation with the James Webb Space Telescope project, I have studied ESD properties of relevant spacecraft materials. I propose to continue my research in order to develop predictions of ESD, based on descriptions of microscopic defect populations in common spacecraft materials. Of particular interest are spacecraft insulators such as polymeric low density polyethylene, polyimide (KaptonTM), and polytetraflourethylene (TeflonTM) as well as ceramics and glasses such as Al2O3 and disordered SiO2 and potential novel nanodielectrics and metamaterials. We have identified different defect species in these materials that affect their breakdown behaviors. These defects include thermally-recoverable low-energy defects and irrecoverable defects associated with energetically deep trap sites. My proposed tests are more applicable to spacecraft technology than standard breakdown tests. Dielectric breakdown strengths cited in handbooks or by manufactures most often come from ASTM standard tests that very rapidly ramp applied voltage until breakdown occurs. These tests are not very repeatable and do not reflect slower charge accumulation rates experienced by spacecraft in the space plasma environment. The MPG ESD test system typically use <1% of these rates, with very repeatable results. For spacecraft charging considerations, it is more useful to talk about how long a material can endure a sub-critical fields before eventual breakdown. The MPG ESD test system is capable of holding samples at sub-critical voltages to observe time to breakdown. My previous experimental work with ESD and time endurance ESD tests has demonstrated differences in pre-breakdown arcing behavior and post-breakdown transport modes between polymeric and glassy materials. These differences reflect differences in intrinsic and induced material defects. My project will entail further experimental work to confirm differences in density and species of defects in different materials and to relate these explicitly to average times to breakdown under field stress. Critical to the development of this model is the understanding of pre-breakdown arcing in terms of the creation and

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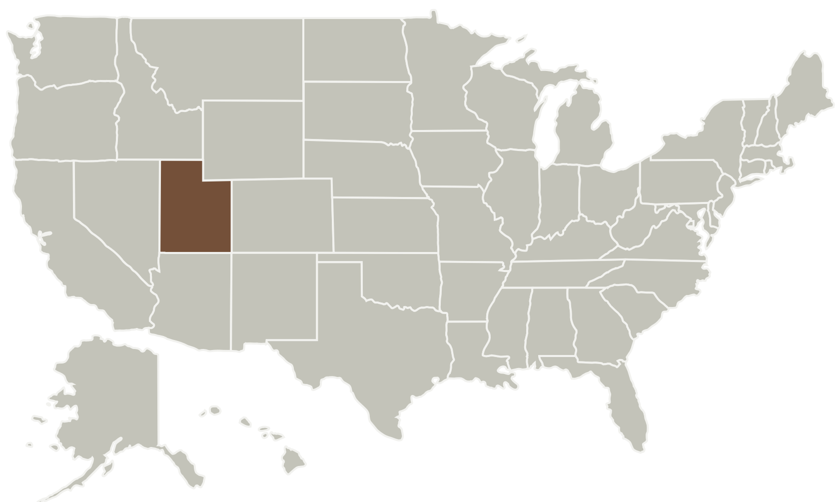
annihilation of recoverable defect sites and the creation of irrecoverable defects. I will extend the MPG time model in terms of these dual defect modes to predict the time to ESD breakdown of insulating materials across differences in temperature, applied field, and thickness as a function of material defect populations. I will test my model against the MPG spacecraft materials database of ESD measurements and MPG constant voltage conductivity and pulsed electro-acoustic charge transport measurements.

Anticipated Benefits

The enhanced time to ESD model will allow for better predictions of spacecraft lifetimes and reduce the time and effort needed to obtain them. Spacecraft in the space plasma environment accumulate charge over time, the lack of electrical ground and low charge mobility can cause strong localized electric fields to build up in a material that can eventually lead to catastrophic breakdown. As spacecraft with longer mission lifetimes and more sensitive instruments are proposed, it becomes increasingly more important to be able to predict the operational lifetime of materials used in harsh space environments. My research will be to perform material tests in order to develop an enhanced ESD breakdown model.

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Utah State University (USU)

Responsible Program:

Space Technology Research Grants

Project Management

Program Director:

Claudia M Meyer

Program Manager:

Hung D Nguyen

Principal Investigator:

Jr Dennison

Co-Investigator:

Allen Andersen

Organizations Performing Work	Role	Type	Location
Utah State University(USU)	Lead Organization	Academia Alaska Native and Native Hawaiian Serving Institutions (ANNH)	Logan, Utah

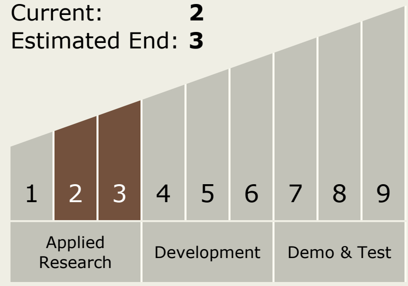
Primary U.S. Work Locations
Utah

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  └ TX12.1 Materials
    └ TX12.1.6 Materials for Electrical Power Generation, Energy Storage, Power Distribution and Electrical Machines

Target Destination

Foundational Knowledge